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REPORT NO. 4-93

EVALUATION OF THE KIN AND DUI PASSIVE THERMAL SURVIVAL SYSTEMS: DEEP DIVE 92

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In the event of power loss to a hyperbaric or personnel transfer capsule, hypothermia can rapidly ensue if thermal protection is not provided. A simulated cooling profile, adopted from a Swedish Navy trial, was used to evaluate the effectiveness of the Diving Unlimited international (DUI) and Seaforth Kinergetics (KIN) passive thermal protection systems at 257 msw. Three data points were obtained for each system. The ability to protect subjects from heat loss, oxygen and carbon dioxide levels within the systems, and functional considerations were addressed.

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ITEM #19 (continued):

One subject remained in the KIN system for 12 hours, the maximum duration of the study. All other trials were terminated due to subject discomfort, rather than low core temperatures or other termination criteria. If the DUI system is used with additional protection from the deck (a mattress), and the KIN with baffles inflated, it appears that greater than 12 hours thermal protection can be expected at 257 msw in a cooling profile scenario. Neither system appeared to provide superior thermal protection over the other if these guidelines were followed. Adequate oxygen levels were supplied by the DUI at 257 msw in a 0.46 ATA PO_2 environment, even though workup experiments showed oxygen levels within the DUI system might be a problem due to the to-fro design of the canister.

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I. INTRODUCTION

Hyperbaric passive thermal survival systems have been developed to minimize core temperature heat loss in the event of loss of power to a hyperbaric chamber or personnel transfer capsule. Navy Experimental Diving Unit, per NAVSEA Task 92-014/015, was tasked to evaluate commercially available hyperbaric passive thermal survival systems. A review of testing on commercial passive thermal survival systems was performed and recommendations made for Navy use.[1] The conclusion of this review was that the Diving Unlimited International (DUI) system had the most favorable overall design; however, initial experiments with the DUI system raised concern that an adequate O_2 level may not be provided due to the increased dead space of the to-fro design.[2] Because of this, it was recommended that the DUI soft scrubber not be used operationally until further studies were conducted.

The DUI and Seaforth Kinergetics Model PSS-04 (KIN) passive thermal survival systems were evaluated at 257 msw (844 fsw), during Deep Dive 92A.[3] The ability of the individual systems to protect a diver exposed to a simulated "lost bell" cooling profile at this depth from hypothermia was addressed, as well as gas levels within the systems and functional considerations.

II. MATERIALS

A. DUI SYSTEM

--Synthetic non-absorbent vacuum packed sleeping bag backed with non-compressible insulation ostensibly designed to eliminate the need for a mattress or air filled device.

--Thermal regenerator/CO_2 scrubber, consisting of an oronasal mask attached to a soft canister via a single corrugated plastic hose (thus the "to-fro" action).

--One-piece Thinsulate coverall including foot coverage.

--Urine collection bag.

B. KIN SYSTEM (APPENDIX B)

--Synthetic non-absorbent vacuum packed sleeping bag backed with an inflatable mattress.

--Thermal regenerator/CO_2 scrubber consisting of an oronasal mask attached to a hard plastic canister.

--Synthetic vest with hood.

--A urine collection device is not included by the manufacturer with the KIN system, thus a condom catheter bag was provided.

III. METHODS

Three simulated lost bell scenario trials were completed, each consisting of two diver-subjects. During each trial, one DUI and one KIN was tested; therefore, three data points were obtained for each system. The divers were exposed to a predetermined cooling profile in Alpha chamber simulating the profile observed by the Swedish Navy (Bell pressurized to 150 msw placed in 2°C water).[4] This profile represents one of the most rapid cooling profiles, thus a "worst case" scenario.

Subjects' age, height, weight and skinfold thickness were all documented during pre-dive workups. Prior to commencing this study, all subjects were exposed to the saturation hyperbaric environment for 16 days. Prior cold exposure included 4-6 dives of twenty to thirty minutes in 2°C water using NRV suits. During these dives, subjects were exposed to ten minutes of cold (4°C) gas breathing; however, rectal temperatures remained essentially unchanged. This prior cold exposure was during the initial 15 days of the Deep Dive, with greater than 48 hours recovery time before exposure in this study.

Instrumentation included temperature probes in the absorbent beds of the CO_2 scrubber/rebreathers (YSI 710 series) and at the inflow to the oronasal masks (YSI 731 series). Inspired gas CO_2 and O_2 at each oronasal mask was sampled via Lee tubing (inside diameter 0.08 cm (1/32")). Data was sampled at 10 Hertz for all KIN gases, and 30 Hertz for the DUI inspired CO_2 and breath-to-breath oxygen analysis. The breath-to-breath analysis of the DUI O_2 was stored as minimum and average values, over 20 second intervals. Canister effluent CO_2 was also measured in the KIN system, but not in the DUI due to the to-fro design. In addition, Alpha chamber CO_2, O_2, and temperature were monitored. Temperature and chamber gas samples were obtained 0.6 m (2 feet) from the deck plates within the chamber. DUI O_2 and CO_2 were analyzed with a Perkin Elmer Mass Spectrometer to allow breath to breath analysis in case O_2 levels dropped too low. KIN oronasal CO_2 and canister effluent CO_2 were monitored with Rosemont 880's, and KIN O_2 with a Rosemont 755R. Chamber O_2 and CO_2 were followed with an Extrel Mass Spectrometer. All gas analyzers were calibrated according to manufacturer's recommendations with primary standards.

The subjects were instrumented with ECG leads, rectal probes (YSI series 701), and skin probes (YSI series 709B) (Appendix C). Each subject wore a t-shirt, sweat shirt, shorts, sweat pants, and socks. After the divers entered Alpha chamber, a partition of Plexiglas was erected between Alpha and Bravo chambers. The Plexiglas partition permitted enough movement of air to keep Alpha chamber at a constant depth throughout the cooling profile. Zero time commenced when the cooling profile was started.

Subjects were instructed at this point to begin preparation of their respective passive thermal survival systems. Although they could postpone donning of the actual sleeping bag system until comfort needs dictated, the expeditious use of the instrumented oral-nasal mask with scrubber was mandatory in an effort to protect the atmosphere of the "bell" from CO_2 buildup. Subjects were instructed to change the CO_2 absorbent every eight hours, or earlier if instructed by the medical deck. In order to provide continuity through the three trials, premeasured and weighed bags of L-grade Sofnolime CO_2 absorbent (4-8 mesh) were available for packing the canisters (DUI-2.7 kg (5.95 lbs), KIN-2.2 kg (4.85 lbs)). Water, high carbohydrate Exceed, and granola bars were

provided for the subjects, but they were never used. Oxygen levels were maintained between 0.44 and 0.48 ATA within Alpha chamber. Carbon dioxide was not scrubbed from the Alpha chamber, so the efficiency of the CO_2 scrubbers in the KIN and DUI systems could be evaluated.

Termination criteria included a core temperature drop to less than 35.50°C for more than one minute; an inspired O_2 of less than 16% SEV for greater than one minute; at the discretion of the principle investigator or diver-subject; or after 12 hours elapsed time in the cooling profile.

Skin probe thermistors were used to monitor and contrast the insulation effectiveness provided by the different system's sleeping bags. Mean skin temperatures were calculated from the skin thermistors using a Hardy/DuBois formula:[5]

$$T_{SKIN} = 0.07(\text{forehead}) + 0.14(\text{forearm}) + 0.05(\text{hand}) + 0.07(\text{foot}) + 0.13(\text{calf}) + 0.19(\text{thigh}) + 0.35(\text{stomach}).$$

Thermistor placement is illustrated in Appendix C.

Rectal temperatures (estimate of body core temperature) were monitored to protect the subjects from hypothermia. This data was plotted against time and analyzed by linear regression. The rate of heat loss, defined as rectal temperature drop over time, was plotted against percent body fat of the subjects to see if adiposity contributed to cold tolerance. The subject's morphometric measurements are in Appendix D.

A questionnaire was administered to each diver every thirty minutes during the trials. Also, a post-dive questionnaire thematically adopted from the Igloo '88 study was administered at the conclusion of the trial.[6] All diver responses to these questionnaires have been compiled and can be found in Appendices E and F.

IV. RESULTS

Due to time required for set up, the delay before subjects utilized their respective scrubber/rebreather ranged from 5 to 13 minutes. The time until

divers were fully within their systems ranged from 50 minutes to 1 hour and 50 minutes. Selected results are listed below:

	Trial #1	Trial #2	Trial #3
Kinergetics			
- Lapse time until in thermal protection	1 hr 03 min	50 min	1 hr 50 min
- Duration	8 hrs 03 min	12 hrs 00 min	9 hrs 39 min
- Rectal temp @ term	35.9°C (96.7°F)	36.4°C (97.1°F)	36.0°C (96.9°F)
- Minimum of average $\%O_2$ SEV in mask	35.95	29.28*	32.19
- Reason for termination	Cold	Time limit	Poor fit of oronasal mask and sinus pressure
Diving Unlimited International			
- Lapse time until in thermal protection	55 min	1 hr 23 min	1 hr 19 min
- Duration	3 hrs 15 min	3 hrs 37 min	7 hrs 04 min
-Rectal temp	36.7°C	37.2°C	36.8°C

@ term	(98.1°F)	(98.9°F)	(98.2°F)
-Minimum of average $\%O_2$ SEV in mask	24.66	28.68	26.35
-Reason for termination	Cold deck on back	Poor fit of oronasal mask	Cold and uncomfortable

*When this decrease was detected, the diver was observed to have the Thermal Regenerator Unit inside the hood of the sleeping bag. After it was taken out, the $\%O_2$ promptly increased (point A and B in Figure 1).

Figure 2 illustrates the target cooling profile used in the Swedish trial, together with the three actual profiles performed in Alpha chamber. The profiles are essentially identical.

A. BODY CORE/SKIN TEMPERATURE

It was felt important to use the systems as the manufacturer advertised, therefore, the DUI was originally used without a mattress or protection from the deck except that provided by the system. The DUI, as outlined under "Materials," is composed of a backing of non-compressible insulation which the manufacturer claims obviates the need for a mattress (Appendix A). However, the first subject in the DUI terminated his run at 3hrs 15min because of subjective feelings of cold and discomfort. This subject commented in his post-dive questionnaire that he could have stayed longer if he had been lifted off the deck. He further states chat he spent much of his time sitting up to avoid the cold deck. After the short duration and comments of DUI subject #1, the remaining DUI participants were required to use a mattress as protection from the deck.

A drop in rectal temperature was produced during the cooling profile regardless of which system was used. Change in rectal temperature from

baseline is expressed graphically in Figures 3 and 4. Figures 5 and 6 demonstrate the same data using absolute rectal temperature (T_{RECTAL}), rather than change in temperature, along the Y-axis.

The calculated T_{SKIN} tended to drop throughout the cooling profile (Figure 7). The coldest individual skin temperature observed during the studies was 16.38°C on the foot of the second KIN subject (the only subject to remain in the cooling profile for the entire 12 hours).

B. ABSORBENT AND ORONASAL GAS TEMPERATURE

Absorbent canister temperatures initially rose to approximately 37°C and remained stable for the remainder of the cooling profile (Figure 8). The sharp decreases noted in two of the KIN runs represent the times when the absorbent was changed. Oronasal gas temperatures remained constant during the studies (Figure 9). The oronasal thermistors were located within the oronasal mask, and therefore would be affected by the divers' expired breath.

C. ORONASAL OXYGEN LEVELS

Average oronasal mask O_2 levels are shown in Figures 10 and 11. Figure 10 contains a comparison of average O_2 levels in the DUI vs. the KIN. The trend for KIN to maintain higher O_2 levels can be seen. As O_2 levels within the DUI were an initial concern based on the to-fro design and earlier experiments[3], Figure 11 contains only the averaged O_2 levels in the DUI. The level of O_2 within the DUI system was very sensitive to movement within the bag and fit of the oronasal mask. While the minimum O_2 in the breath-to-breath analysis during the three trials was 20.48% SEV, the lowest 20 second average was 23.17% SEV.

Due to the configuration of the KIN system and location of the thermal regeneration unit, major drops in average oronasal O_2 were noted when the subjects inadvertently covered this unit with the sleeping bag hood. This system works by dumping CO_2 scrubbed expired gases out through this thermal regenerator unit into the atmosphere. This unit is warmed as these expired gases pass through it. Inhaled air is then pulled in through this thermal

regenerator unit, and thereby warmed. In Figure 1, points A and B represent times when the subjects were observed to have the unit within the hood. After removing the unit from the sleeping bag, O_2 levels rapidly increased as shown.

D. CHAMBER ATMOSPHERE

Chamber atmosphere CO_2 gradually increased during the cooling profile, but remained well below 1% SEV, even after extrapolating the slope of rise to 24 hours.

E. HUMAN FACTORS

Overall, the subjects reported general satisfaction with ability to assemble and don both systems; temperature of the breathing gas; comfort of the oronasal mask; and ability to breath with the units. Comfort of the sleeping bag system was a major topic of complaint, particularly with the KIN system.

All subjects remained without symptoms of hypoxia or CO_2 intoxication (including air starvation, loss of consciousness, headache, burning eyes, mental confusion, or shortness of breath) throughout the series.

V. DISCUSSION

Definitive conclusions about the efficacy of these two systems, based on the length of time these subjects stayed in them, can not be drawn with such a small sample size. The reasons for termination during this study were usually related to comfort, something greatly affected by individual differences and the perceived threat of a situation. Someone in a genuine lost bell situation would care much less about an uncomfortable mask than one would in a controlled experimental situation. Nevertheless, trends in rate of heat loss, gas concentrations, scrubbing capabilities, and functional considerations can be addressed.

A. BODY CORE/SKIN TEMPERATURE

Changes in diver core temperatures are found in Figures 3-6. Subjects exhibited slight increases in their body core temperature early in the cooling profile, due to the work required from them to prepare their systems in an atmosphere that was not yet very cool. This initial increase was excluded in the trend analysis of the data. Linear regression lines are provided corresponding to each subjects' temperature change. Since the number of runs and times are limited, caution should be exercised when interpreting these lines, particularly with the shorter runs. Regression coefficients show a strong linear trend, however.

Figures 3 and 5 represent all three runs in the DUI system. Subject #1, who did not use a mattress, lost body heat at a considerably higher rate than the subsequent subjects, who were required to use a mattress. Figures 4 and 6 represent all three runs in the KIN system. Again, subject #1 lost heat at a greater rate than the other subjects. Review of the logs revealed that he deflated the KIN air baffles after five minutes because they were quite uncomfortable. The other KIN subjects kept the baffles inflated throughout the cooling profile. To determine if cooling rate might be related to body type rather than contact with the deck, rate of heat loss for each run was calculated in °C/hr. These calculated cooling rates for subjects in each system were plotted against body fat composition. No relationship was found (Figure 12).

Assuming a linear rate of heat loss and proper use of the systems, it appears both the KIN and DUI system can be expected to maintain body core temperatures above 35.5°C for at least 12 hours at 257 msw in a "cooling profile" scenario (provided the DUI is used with additional protection from the deck, and baffles are inflated on the KIN). Impairment of function usually begins at core temperatures less than 35°C.[7] Subjects commented that even short durations outside the sleeping bag were difficult. In their words, "Canister change out was a killer. You go numb when you get out of the bag." (Appendix F).

Although the subject's core temperature may be maintained with either system, cold discomfort may cause a decrement of performance. This factor may be critical during the recovery of a "lost bell." It is recommended that future studies incorporate psychophysical measurements.

B. ABSORBENT AND ORONASAL GAS TEMPERATURE

The KIN system appears to maintain higher oronasal gas temperatures, although subjects in both systems were subjectively satisfied with the gas temperatures (Appendix E).

C. ORONASAL OXYGEN LEVELS

The DUI system appears to maintain adequate oronasal O_2 levels, although these were measurably lower than the KIN system.

If the Thermal Regenerator Unit of the KIN system is not kept out of the hood of the sleeping bag system, the oronasal mask is prone to decreased O_2 levels (although not to a critical level in this series). The assembly instructions provided with the system show a picture of the Thermal Regenerator Unit out of the bag, but do not specifically instruct users to keep the unit out.

D. CHAMBER ATMOSPHERE

Chamber atmosphere is adequately protected with the scrubber/rebreather systems provided.

E. HUMAN FACTORS

The KIN system has two design characteristics that subjects consistently commented reduced their comfort level. First, the baffles only extended to the waist, which decreased insulation for the lower extremities, as well as providing an uncomfortable drop for the waist and legs as they "fell off" the baffles support. This, combined with the lack of inner pants or other leg

protection, contributed to lower extremity exposure to the cold deck and decreased diver comfort.

Both systems need to be modified to be slightly larger to better accommodate larger individuals, as shown in the post-dive questionnaire.

VI. CONCLUSIONS

Neither the KIN or DUI appears to provide superior thermal protection over the other. However, the DUI system should be used with additional protection from the deck (i.e., mattress), or with a hammock type apparatus. The KIN system should be used with the baffles inflated. Under these conditions it appears that greater than 12-hour thermal protection can be expected at 257 msw in a "cooling profile" scenario.

Adequate Oxygen levels are supplied by the DUI at 257 msw in a 0.46 ATA PO_2 environment. However, more studies are required before any definite conclusion can be made. Care should be taken when using the KIN system to make sure the Thermal Regenerator Unit is kept outside the sleeping bag hood to maintain optimal PO_2 levels.

Comfort of the KIN system could be enhanced by modifying the air baffle system, and providing additional thermal protection for the lower extremities.

REFERENCES

1. NEDU ltr 3963/TA91-007 Ser 0724/010 of 3 Jan 92.

2. Paul C. Kelleher, *Evaluation of the Diving Unlimited International (DUI) Hyperbaric Passive Thermal Protection System: Inspired Oxygen Levels at 36 FSW (0.44 ATA PO_2)*, TM 92-14, Navy Experimental Diving Unit, 16 June 1992.

3. Navy Experimental Diving Unit, *Protocol Deep Dive 92*, Manned OSF Protocol Number 92/38, September 1992.

4. J. Magnusson et al., "Metabolic Rate of Divers in a Simulated 'Lost Bell' Survival Test," *Underwater Physiology VIII*, Undersea Medical Society, Bethesda, Maryland, pp 349-360, 1984.

5. J.D. Hardy, and E.F. DuBois, "The Technique of Measuring Radiation and Convection," *Journal of Nutr.* 15: pp 461-475, 1938.

6. National Hyperbaric Centre, "Evaluation of Survival Systems," *Igloo 88 Dive Report*, TRPO: 02890, Vol 2, National Hyperbaric Centre, Aberdeen, Scotland, April 18, 1989, pp. 88-110.

7. T. J. Doubt, and M.D. Curley, *Proceedings of the 1991 NSW Thermal Workshop*, Naval Medical Research Institute, NMRI 92-84, September 1992.

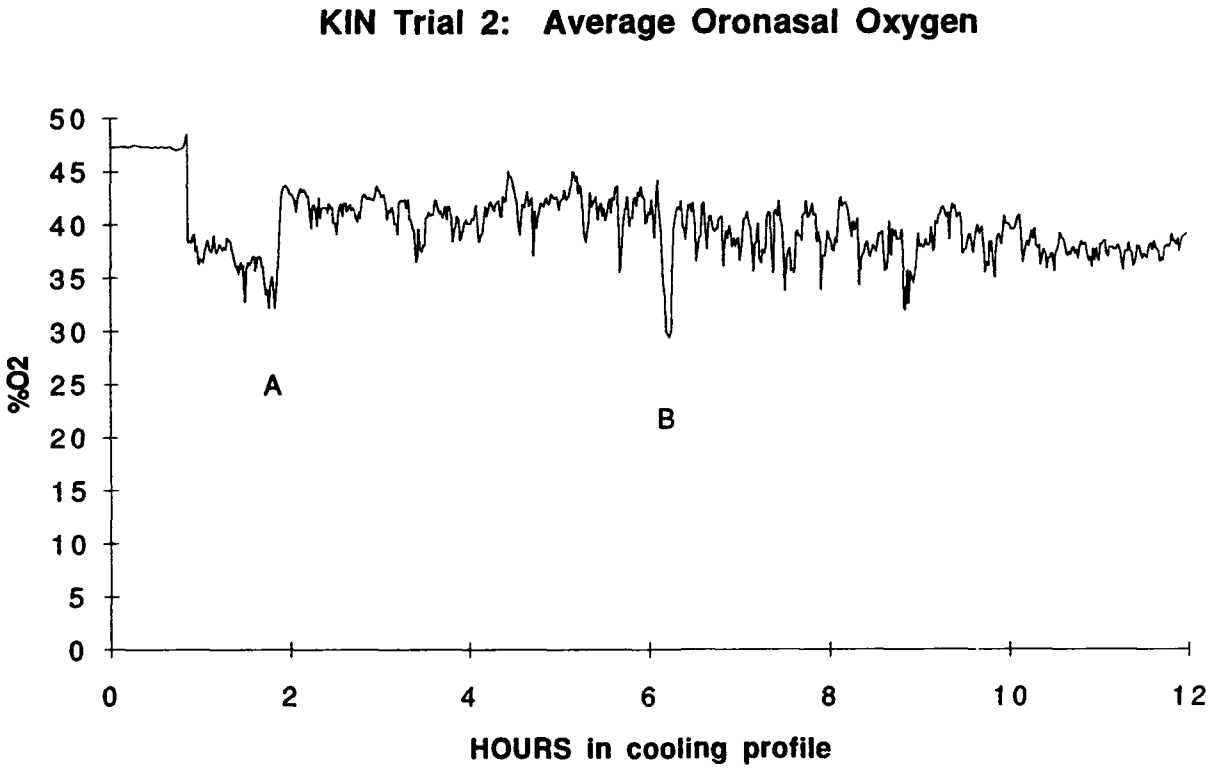


FIGURE 1. POINTS A AND B REPRESENT ORONASAL OXYGEN LEVELS WHEN THE THERMAL REGENERATOR UNIT WAS INSIDE THE SLEEPING BAG. ONCE REMOVED, OXYGEN LEVELS PROMPTLY INCREASED.

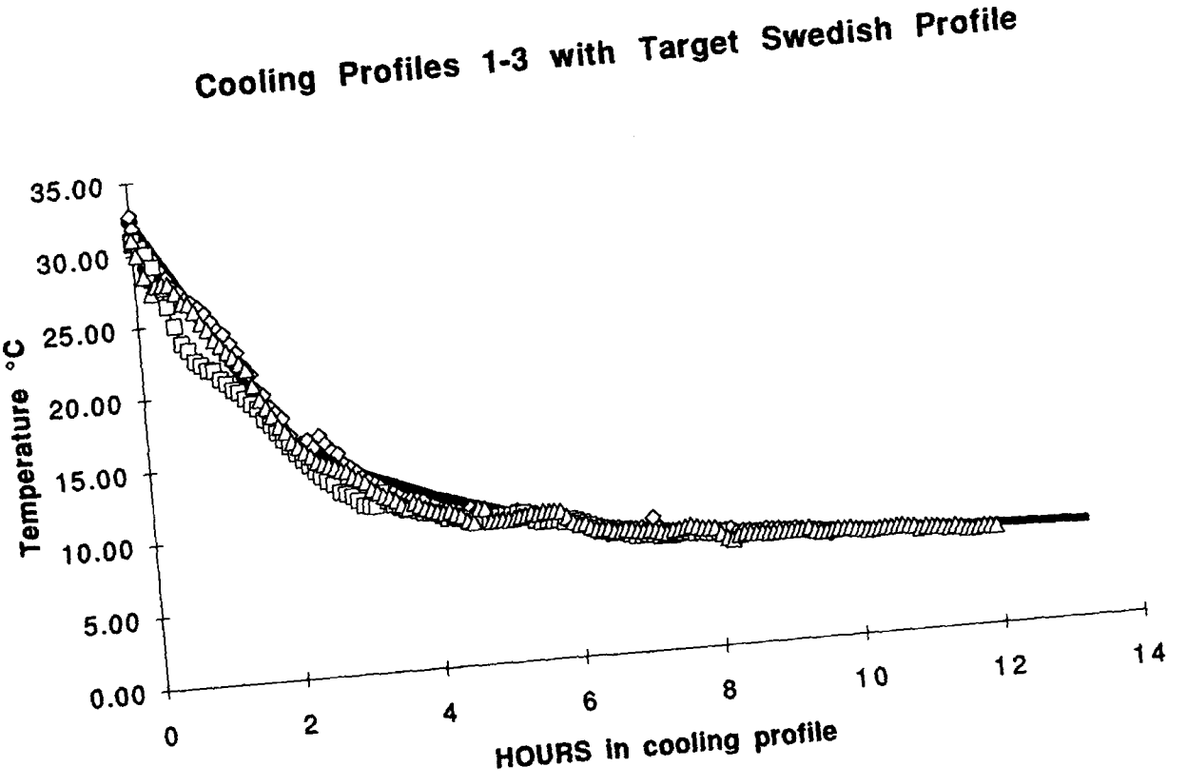


FIGURE 2. THE TARGET SWEDISH PROFILE IS REPRESENTED BY THE BOLD BLACK LINE. TRIALS 1, 2, AND 3 ARE REPRESENTED BY THE SQUARE, TRIANGLE, AND DIAMOND RESPECTIVELY.

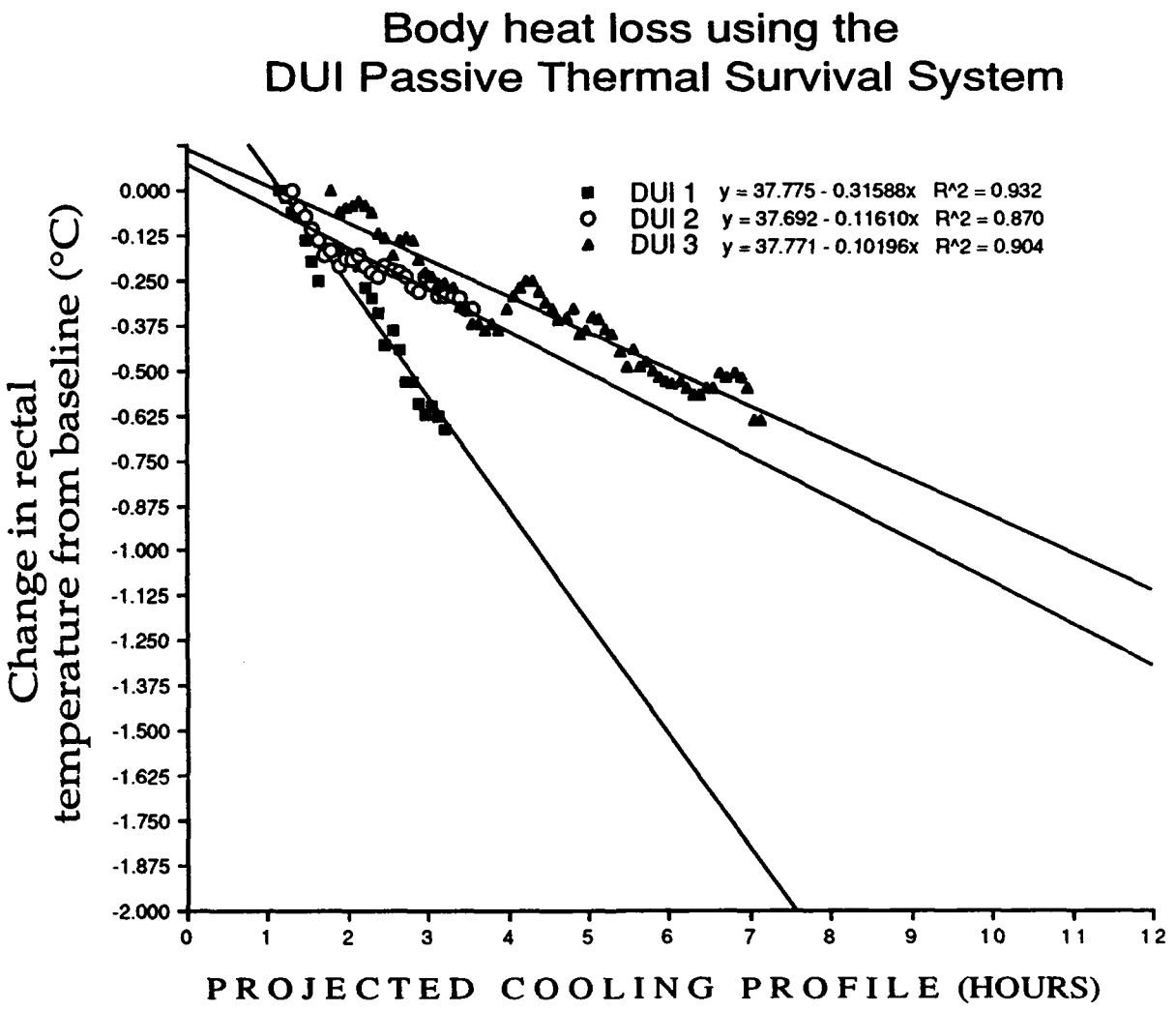

Body heat loss using the
DUI Passive Thermal Survival System
DUI 1 y = 37.775 - 0.31588x R^2 = 0.932
DUI 2 y = 37.692 - 0.11610x R^2 = 0.870
DUI 3 y = 37.771 - 0.10196x R^2 = 0.904
Change in rectal temperature from baseline (°C)
0.000
-0.125
-0.250
-0.375
-0.500
-0.625
-0.750
-0.875
-1.000
-1.125
-1.250
-1.375
-1.500
-1.625
-1.750
-1.875
-2.000
0 1 2 3 4 5 6 7 8 9 10 11 12
PROJECTED COOLING PROFILE (HOURS)

FIGURE 3.

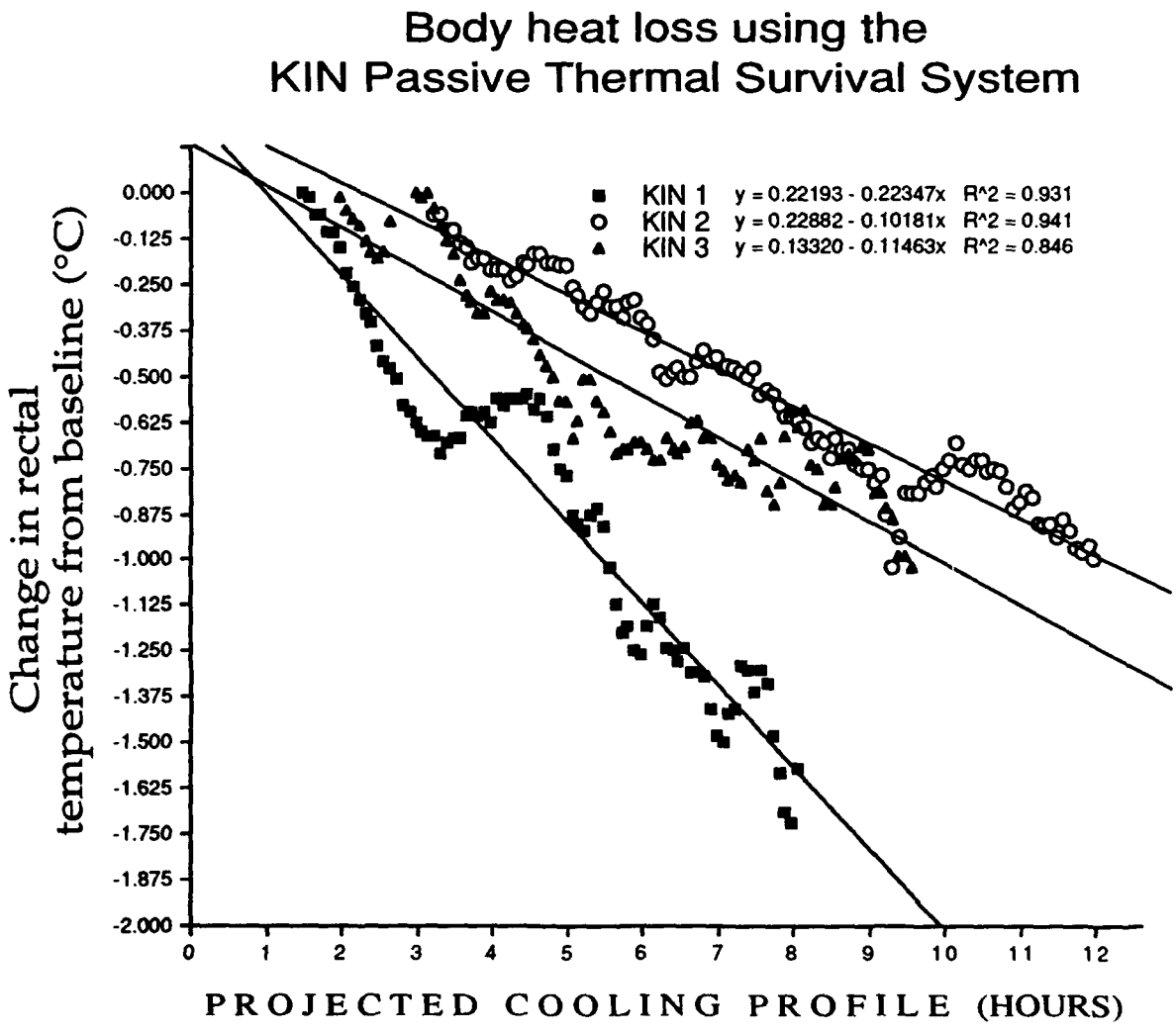

Body heat loss using the
KIN Passive Thermal Survival System
KIN 1 y = 0.22193 - 0.22347x R^2 = 0.931
KIN 2 y = 0.22882 - 0.10181x R^2 = 0.941
KIN 3 y = 0.13320 - 0.11463x R^2 = 0.846
Change in rectal temperature from baseline (°C)
0.000
-0.125
-0.250
-0.375
-0.500
-0.625
-0.750
-0.875
-1.000
-1.125
-1.250
-1.375
-1.500
-1.625
-1.750
-1.875
-2.000
0 1 2 3 4 5 6 7 8 9 10 11 12
PROJECTED COOLING PROFILE (HOURS)

FIGURE 4.

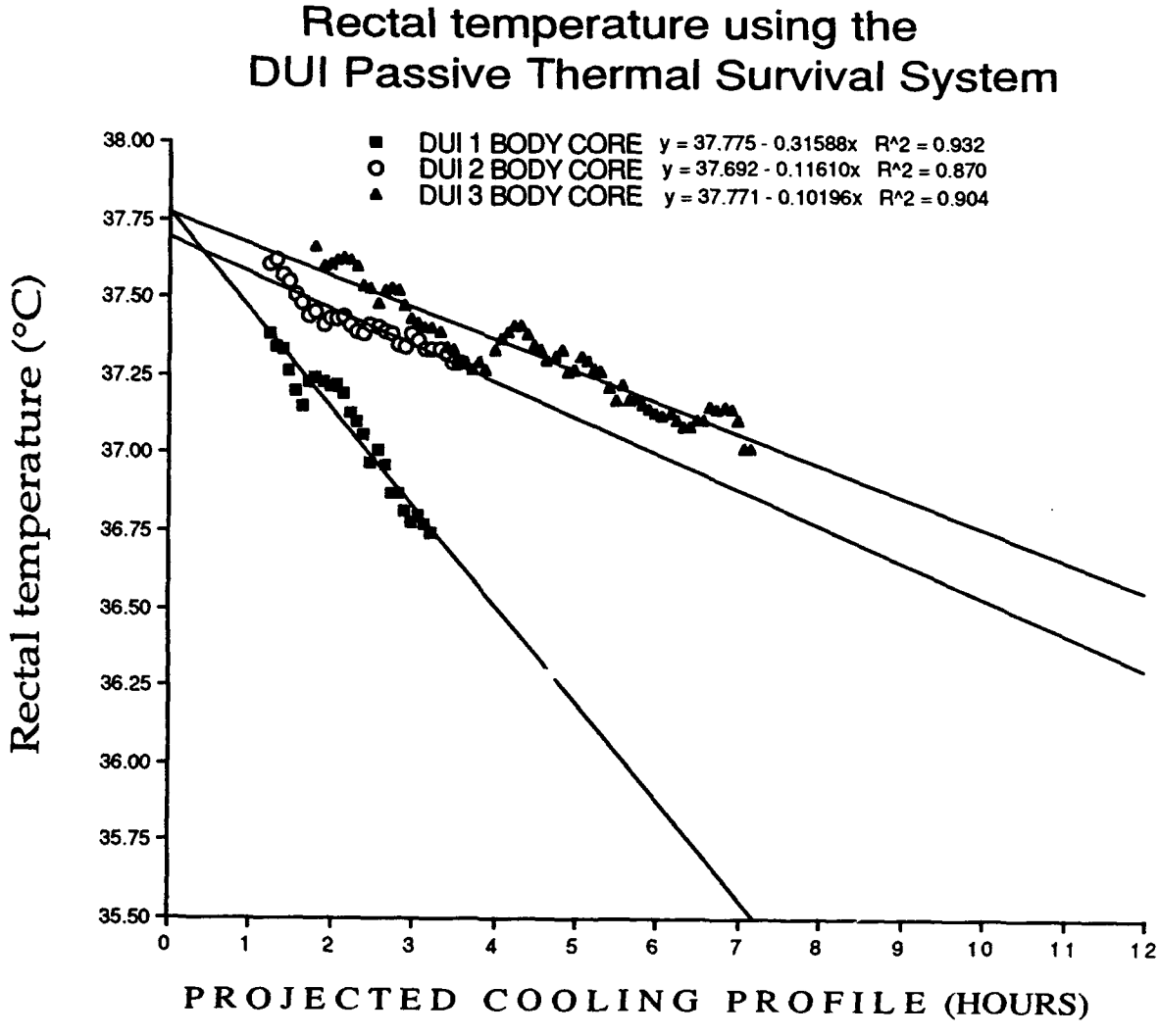

Rectal temperature using the
DUI Passive Thermal Survival System
DUI 1 BODY CORE y = 37.775 - 0.31588x R^2 = 0.932
DUI 2 BODY CORE y = 37.692 - 0.11610x R^2 = 0.870
DUI 3 BODY CORE y = 37.771 - 0.10196x R^2 = 0.904
Rectal temperature (°C)
38.00
37.75
37.50
37.25
37.00
36.75
36.50
36.25
36.00
35.75
35.50
0
1
2
3
4
5
6
7
8
9
10
11
12
PROJECTED COOLING PROFILE (HOURS)

FIGURE 5.

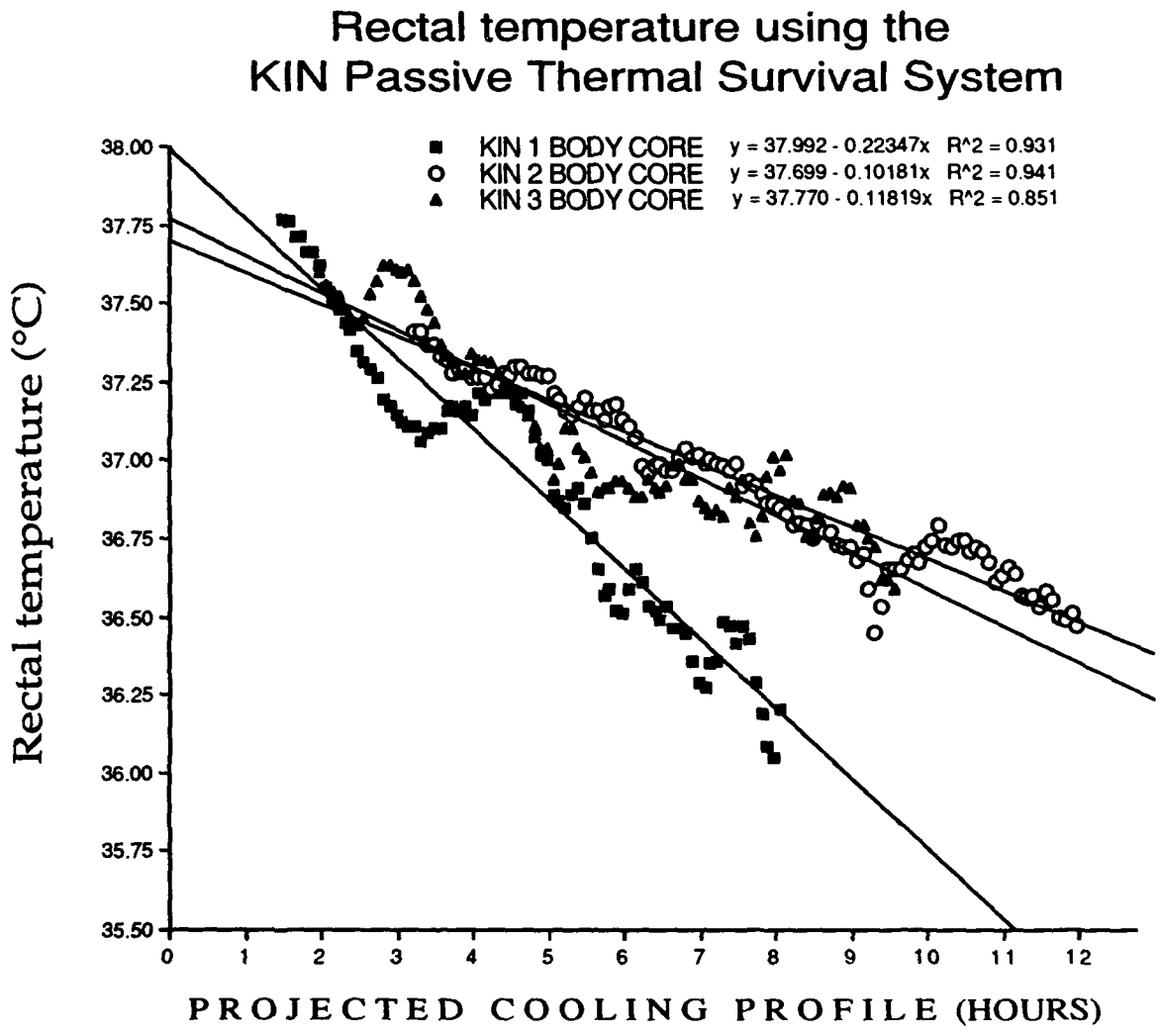

Rectal temperature using the
KIN Passive Thermal Survival System
KIN 1 BODY CORE y = 37.992 - 0.22347x R^2 = 0.931
KIN 2 BODY CORE y = 37.699 - 0.10181x R^2 = 0.941
KIN 3 BODY CORE y = 37.770 - 0.11819x R^2 = 0.851
Rectal temperature (°C)
38.00
37.75
37.50
37.25
37.00
36.75
36.50
36.25
36.00
35.75
35.50
0
1
2
3
4
5
6
7
8
9
10
11
12
PROJECTED COOLING PROFILE (HOURS)

FIGURE 6.

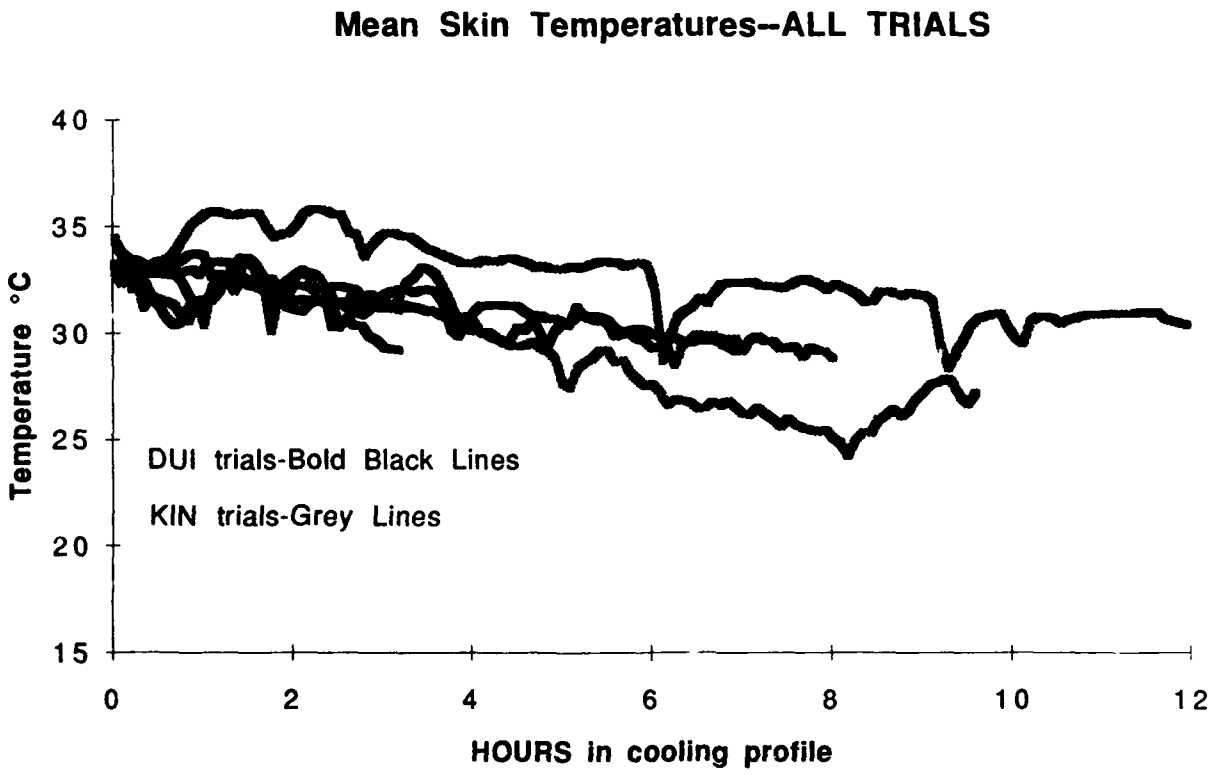

Mean Skin Temperatures--ALL TRIALS
Temperature °C
40
35
30
25
20
15
DUI trials-Bold Black Lines
KIN trials-Grey Lines
0
2
4
6
8
10
12
HOURS in cooling profile

FIGURE 7.

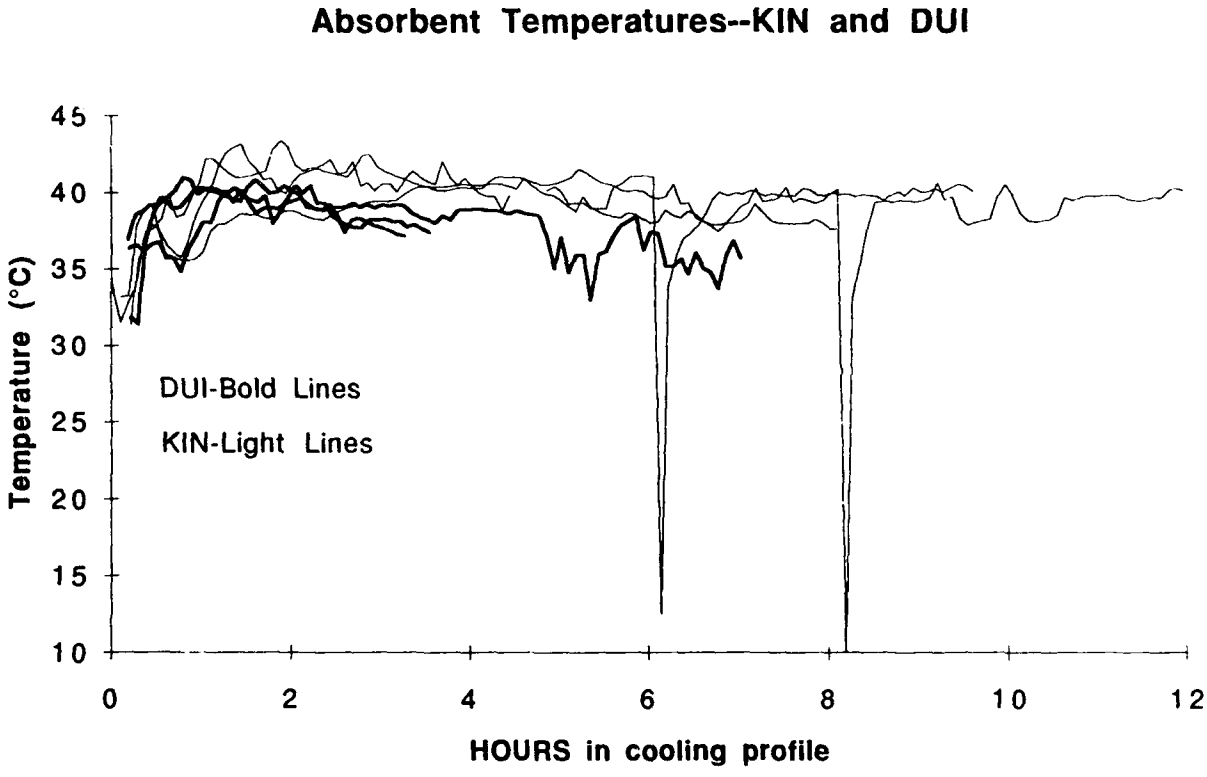


FIGURE 8. THE TWO DIPS IN THE KIN TEMPERATURES REPRESENT TIMES WHEN THE CANISTER ABSORBENT WAS CHANGED.

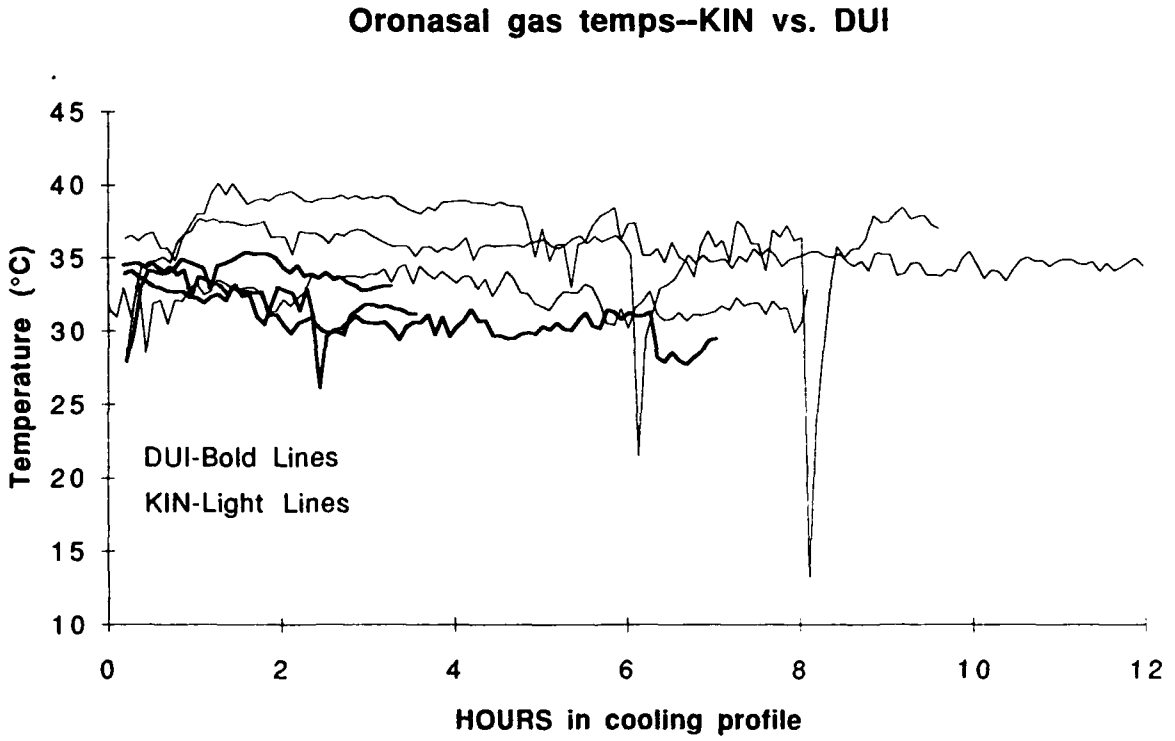


FIGURE 9. THE TWO LARGE DIPS ARE TIMES WHEN ABSORBENT WAS CHANGED.

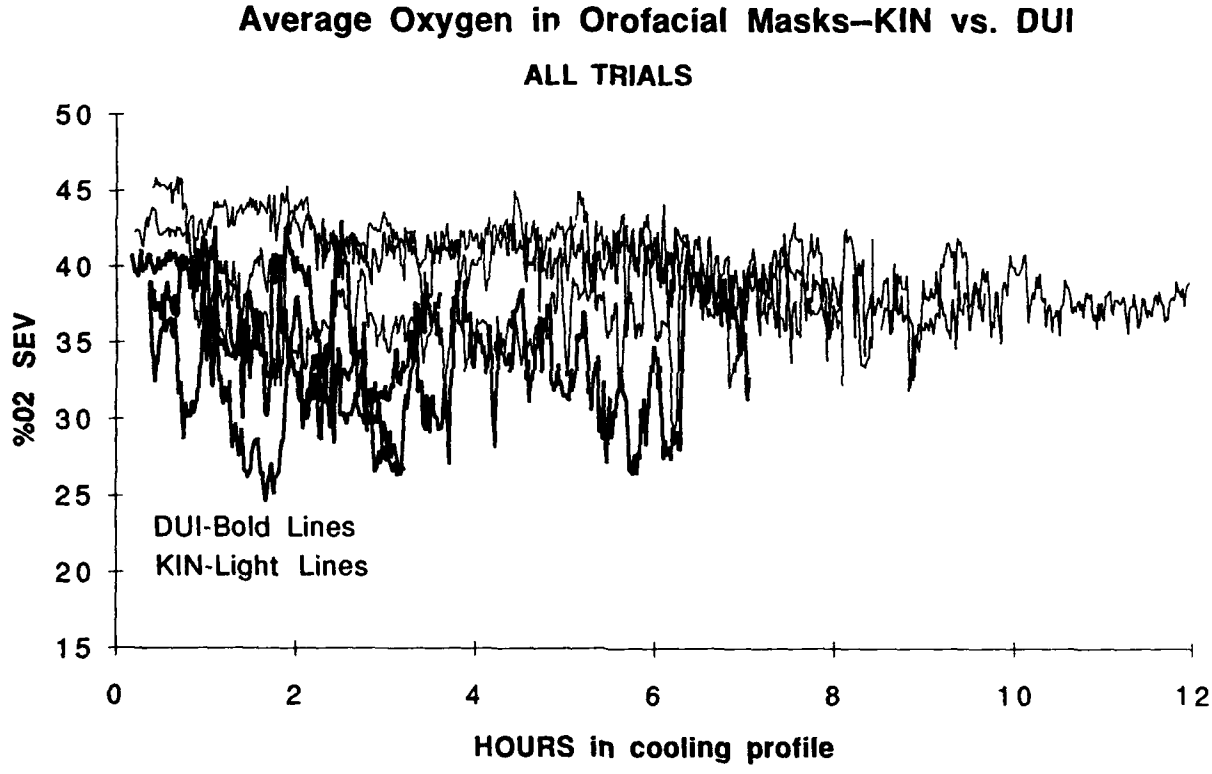

Average Oxygen in Orofacial Masks--KIN vs. DUI
ALL TRIALS
%02 SEV
50
45
40
35
30
25
20
15
DUI-Bold Lines
KIN-Light Lines
0
2
4
6
8
10
12
HOURS in cooling profile

FIGURE 10.

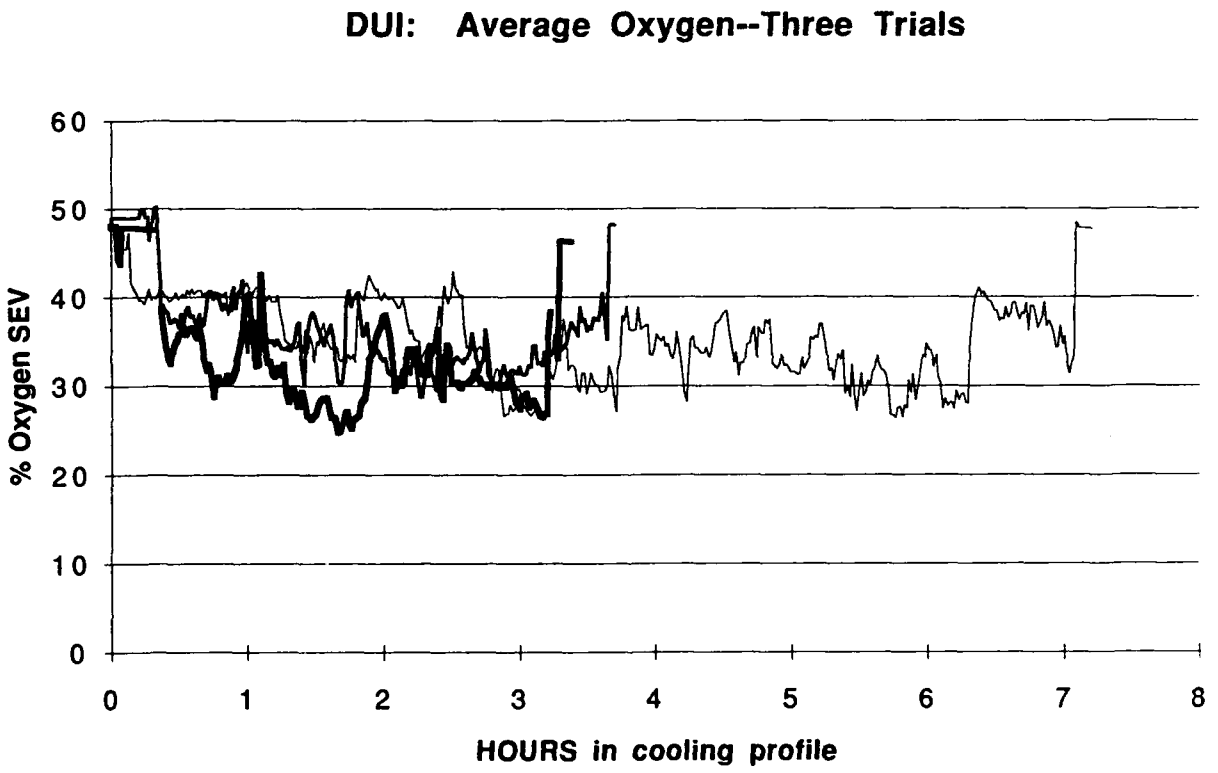

DUI: Average Oxygen--Three Trials
% Oxygen SEV
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
HOURS in cooling profile

FIGURE 11.

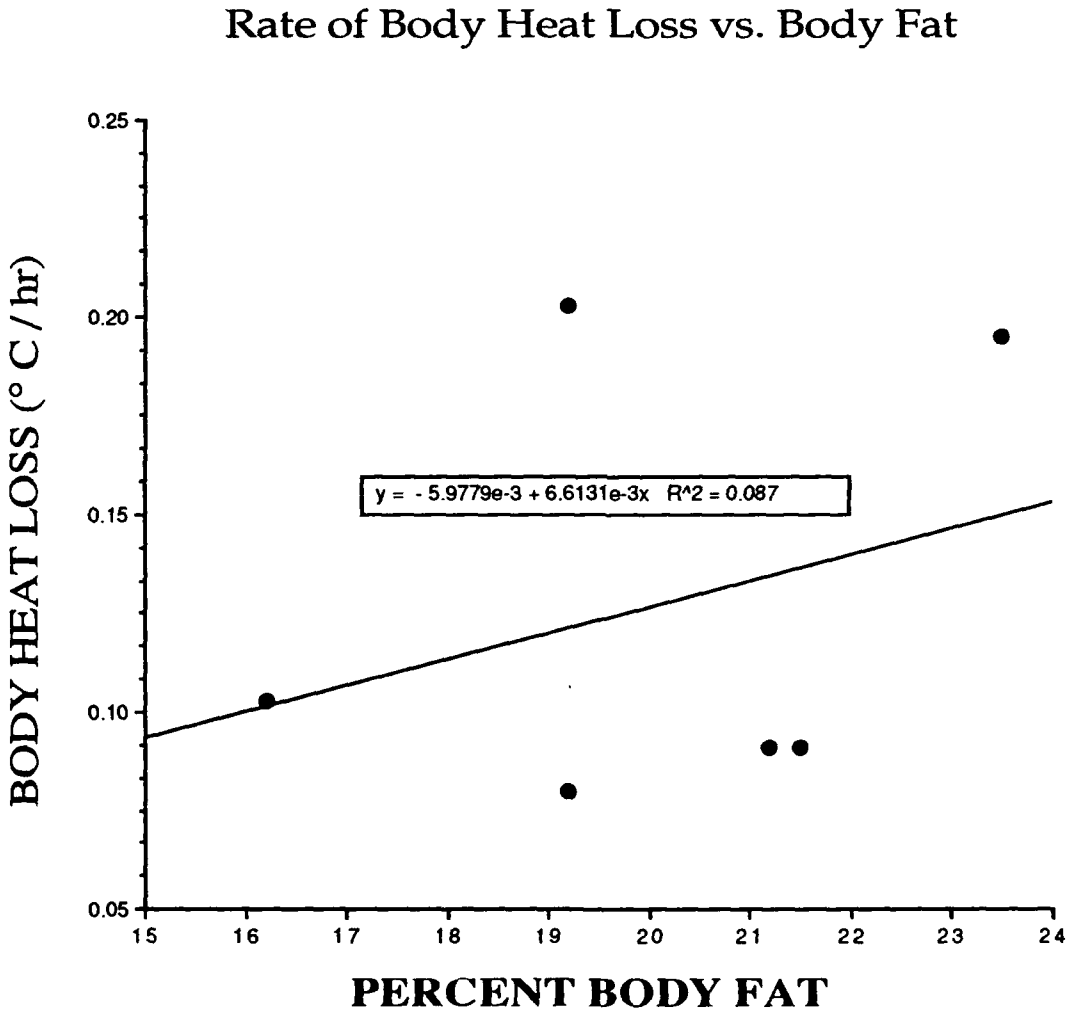

Rate of Body Heat Loss vs. Body Fat
BODY HEAT LOSS (° C / hr)
0.25
0.20
0.15
0.10
0.05
y = - 5.9779e-3 + 6.6131e-3x R^2 = 0.087
15
16
17
18
19
20
21
22
23
24
PERCENT BODY FAT

FIGURE 12.

DUI®
INC

DUI POLAR BEAR II

Three years of testing, research and real world experience brought out a number of problems experienced by all known bell survival systems. DUI has effectively addressed these problems in the Polar Bear II system.

SYSTEM COMPONENTS

SLEEPING BAG CONSTRUCTION

- All plastic Delrin non-corrosive zippers and slides
- Thinsulate insulation reduces water ingress providing excellent insulation qualities.
- The M4 non-compressible insulation in the back of the sleeping bag eliminates the mattress and the need to rely on air filled devices.
- Narrow leg and foot section design reduces gas pumping.

THE COVERALL

- One piece Coverall provides total body protection during bell cool down and set up while operating valves or communications equipment.
- Can be used in deck chambers and life boats.
- Designed for simple immediate use.

PACKAGING

- Reduced size
- Eliminated mattress tube
- Easier opening

NEW DUI SOFT CO^2 SCRUBBER

DUI® INC

SOFT DESIGN ADVANTAGE - Soda Sorb can be further activated by pounding on the soft canister with the palms of the hands to increase use time.

COMFORT/SIMPLICITY - The mask, with its pull-tab adjustments, offers extreme comfort including a new canister support design which places the canister weight on the neck.

VERSATILITY - Only the DUI System can be used in a high $C0^2$ atmosphere.

PACKING KNOWLEDGE - Canister can be filled easily, by the unfamiliar, and our unique compression system insures against channeling.

EASY FILL DESIGN - Canister can be sent down empty with separate supply of Soda Sorb, filled at the surface, or during the dive. Either with a fraction of the time previously needed.

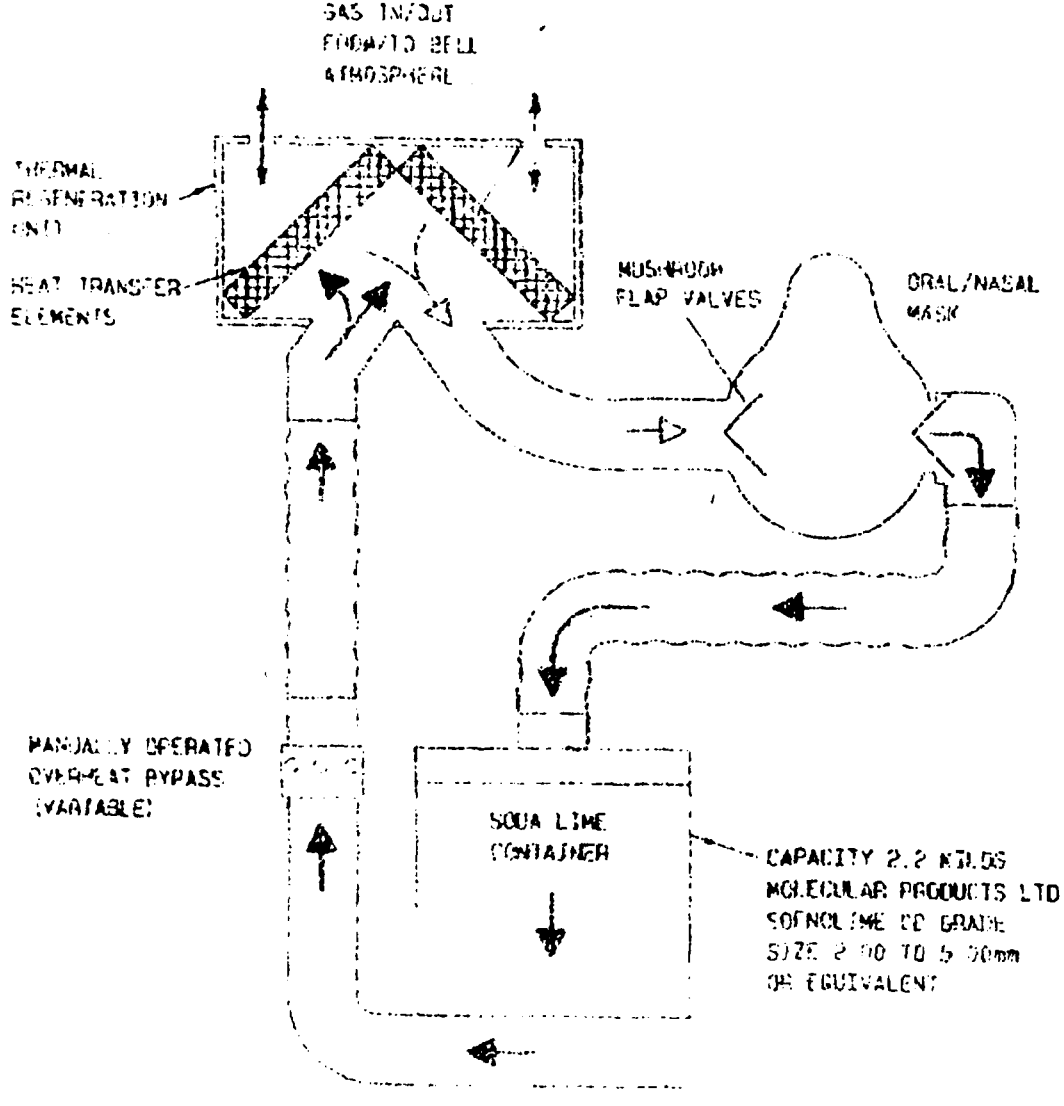
CANISTER VOLUME - The new soft canister can hold 6½ plus pounds.

0^2 DEAD SPACE - Because of the unique to/fro design and large surface area the 0^2 and $C0^2$ dead space has been minimized. The Dwell Time in the Bed has been increased dramatically.

DIVING UNLIMITED INTERNATIONAL, INC.
1148 Delevan Drive • San Diego, CA 92102 • Phone: (619) 236-1203 • Telex: 697971

DUI LIMITED • Advance Unit 8
Fairburn Industrial Est • Dyce, Aberdeen • Phone: (224) 724093 • Telex: 739130

2918 mm DO NOT SCALE IF IN DOUBT ASK



SEAFORTH KINERGETICS QUALITY CONTROL

DESIGN AND MANUFACTURE OF ALL MATERIAL SPECIFIED ON THIS DRAWING TO BE IN ACCORDANCE WITH THE UNDERNOTED CLASSIFICATION SOCIETY REQUIREMENTS

LEGEND :-

→ REGENERATED GAS

← EXHALED GAS

DRAWN TO BS308

REV No.	BY	DATE	ISSUED FOR APPROVAL	APP'D
D	RAS	2/1/91		

Seaforth Kinergetics

PROJECT TITLE: THERMAL REGENERATION SYST

TITLE: FLOW DIAGRAM MODEL TRS-01

DRAWN BY: D.A.S.EWART 2/1/91

CHECKED BY: RAS

APPROVED BY: 2/1/91

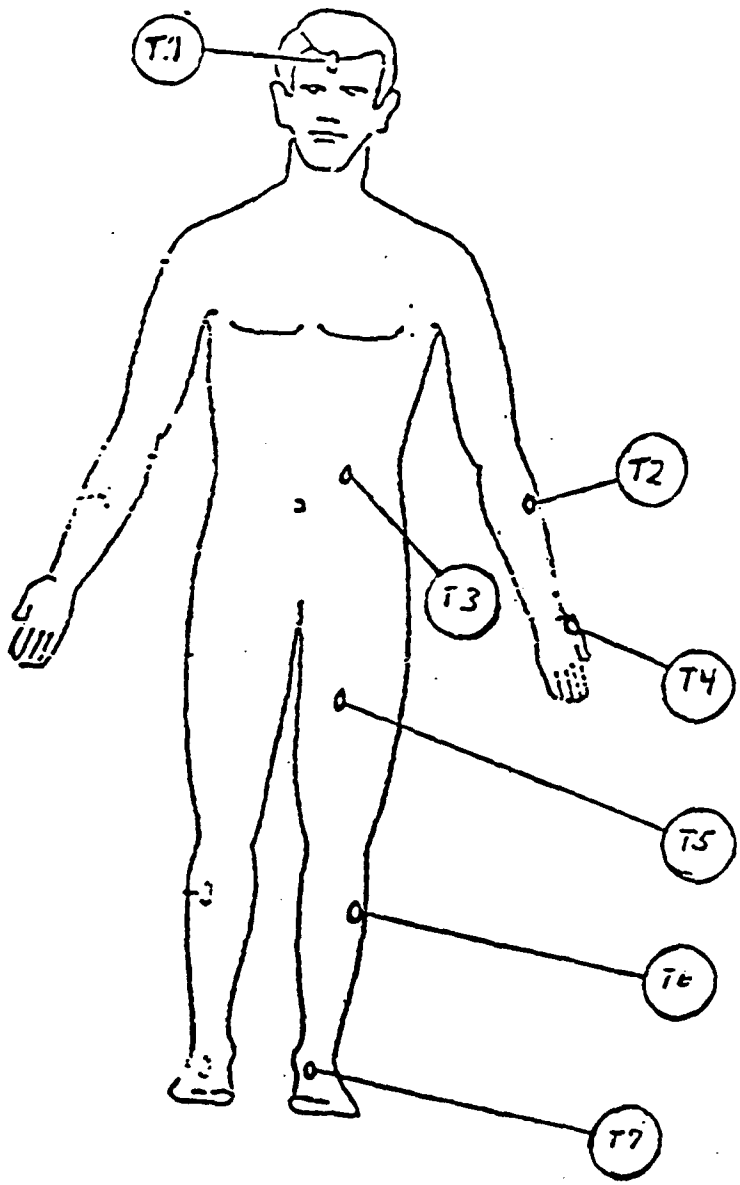
STATUS: NTS

DRG No. 8162

APPENDIX B

APPENDIX C

SKIN PROBE THERMISTOR PLACEMENT DIAGRAM



PRE-DIVE MORPHOMETRIC MEASUREMENTS
DD '92A PASSIVE THERMAL SURVIVAL SUBJECTS

Subject	*Initial*	*Age*	*Weight* (Kg)	*Height* (cm)	Skin Fold Measurements (mm) *Biceps*	*Triceps*	*Suprailiac*	*Subscapular*	% BF age adjusted
KIN									
# 1	V	31	177.8	83.6	3.5	22.5	22	14	23.5
# 2	Ba	30	175.3	88.2	5	7	18	10	19.2
# 3	J	32	182.9	80.9	4.2	4	13	11	16.9
DUI									
# 1	H	38	175.3	73.6	8	7	15	10	19.2
# 2	S	31	175.3	95.9	7.5	12	18	14	21.5
# 3	BI	25	175.3	80.9	7	9	22.5	19	20.7

ANSWERS TO

QUESTIONNAIRE FOR ANNEX A8--DD'92

Lost PTC Scenario, Passive Thermal Survival Systems

	DUI-GRN			KIN-RED		
Subjects:	H	S	BI	V	Ba	J

1. ARE YOU COMFORTABLE?

1 2 3 4 5 6 7 8 9 10

Very Uncomfortable — Most Comfortable

DUI-GRN
H-- 8, 8, 5, 6, 4, 4
S-- 5, 5, 5, 5, 4, 3, 3
BI-10, 5, 5, 5, 4, 5, 5, 4, 4, 4, 3, 3, 3, 2

KIN-RED
V--10,10, 5, 1, 5, 5, 5, 3, 4, 5, 5, 1, 1, 1, 1, 1
Ba-10, 6, 4, 5, 4, 5, 4, 6, 4, 4, 4, 4, 4, 4, 4, 4, 4, 3, 4, 4, 3, 3, 3, 3
J-- 8, 8, 8, 8, 8, 7, 6, 5, 4, 6, 4, 4, 3, 3, 3, 3, 3, 3, 3

2. ARE YOU WET? (Perspiration)

1 2 3 4 5 6 7 8 9 10

Dry — Completely Wet

DUI-GRN
H--7, 5, 5, 5, 5, 5
S--1, 1, 1, 1, 2, 2, 2
BI-1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1

KIN-RED
V-- 2, 2, 1, 1, 1, 2, 2, 2, 1, 1, 1, 1, 2, 1, 2, 1,
Ba-1, 3, 2, 2, 3, 2, 2, 2, 2, 2, 2, 1, 2, 1, 2, 2, 2, 2, 2, 2, 2, 2, 2, 2
J-- 1, 1, 1, 1, 1, 2, 2, 2, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1

3. ARE YOU COLD OR HOT?

1 2 3 4 5 6 7 8 9 10

Very Cold — Perfect — Very Hot

DUI-GRN
H--6, 8, 5, 7, 3, 2
S--5, 6, 5, 5, 4, 4, 3
BI-6, 5, 5, 4, 4, 4, 4, 4, 4, 4, 3, 3, 2, 2

KIN-RED
V-- 5, 8, 5, 3, 3, 3, 3, 1, 1, 1, 1, 1, 1, 1, 1, 1
Ba-7, 7, 6, 6, 4, 4, 4, 4, 4, 4, 4, 4, 5, 5, 4, 4, 4, 3, 4, 4, 3, 3, 3, 4
J-- 5, 4, 5, 5, 5, 4, 4, 4, 4, 4, 3, 3, 3, 3, 3, 3, 3, 3, 3

4. ARE YOU SHIVERING?

1	2	3	4	5	6	7	8	9	10
Absent									Most Shivering

DUI-GRN
H--1, 1, 1, 1, 5, 9
S--1, 1, 1, 1, 1, 1, 3
Bl-1, 1, 1, 1, 1, 1, 1, 1, 2, 1, 2, 3, 4, 4

KIN-RED
V-- 1, 1, 1, 1, 4, 7, 7, 7, 1, 2, 1, 8, 7, 7, 5, 6,
Ba-1, 1, 1, 1, 1, 1, 1, 2, 2, 3, 1, 2, 1, 1, 1, 2, 1, 2, 2, 1, 3, 5, 4, 3
J-- 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 2, 2, 2, 3, 3, 3, 3, 3, 3

5. IS THE MASK COMFORTABLE?

1	2	3	4	5	6	7	8	9	10
Least									Most Comfortable

DUI-GRN
H--6, 5, 5, 5, 5, 5
S--3, 3, 3, 3, 1, 1, 1
Bl-6, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4

KIN-RED
V-- 5, 5, 2, 3, 5, 5, 5, 5, 4, 5, 5, 5, 5, 3, 4, 5
Ba-5, 5, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4, 4
J-- 8, 5, 6, 6, 6, 6, 5, 5, 5, 5, 4, 4, 4, 4, 4, 4, 4, 4, 4

6. IS THE GAS COLD OR HOT?

1	2	3	4	5	6	7	8	9	10
Very Cold				Perfect					Very Hot

DUI-GRN
H--5, 5, 7, 6, 5, 5
S--6, 6, 5, 5, 6, 6, 5
Bl-6, 6, 6, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5, 5

KIN-RED
V-- 5, 7, 6, 5, 6, 7, 5, 5, 5, 5, 5, 4, 4, 3, 3, 5
Ba-6, 7, 7, 7, 5, 6, 5, 5, 5, 4, 5, 5, 5, 5, 5, 5, 4, 4, 4, 4, 4, 4, 4, 4
J-- 4, 5, 6, 6, 6, 5, 5, 5, 5, 5, 5, 5, 4, 4, 5, 5, 5, 5, 5

7. WILL YOU QUIT SOON? Y / N

DUI-GRN
H--N,N,N,N,N,Y
S--N,N,N,N,M,N,N
Bl-N,N,N,N,N,N,N,N,N,N,N,N,Y,Y

KIN-RED
V-- N,N,N,N,N,M,N,N,N,N,N,N,M,M,Y,Y
Ba-N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,M,N,N,N,N,N,N
J-- N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N

8. DO YOU WISH TO QUIT NOW? Y / N

DUI-GRN
H--N,N,N,N,N,Y
S--N,N,N,N,N,N,Y
BI-N,N,N,N,N,N,N,N,N,N,N,N,N,Y

KIN-RED
V-- N,N,N,N,N,N,N,N,N,N,N,N,N,N,Y
Ba-N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N--12 Hours elapsed--Dive Terminated
J-- N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N,N--Terminated 10' later.

APPENDIX F

ANNEX A8
Passive Thermal Survival System
Post-Dive Questionnaire
ANSWERS

Subjects: H S Bl V Ba J

(1) How difficult was the suit to get on; suggestions on improvements?

DUI H-Easy to put on. The zipper on the bag could be longer and come up further.
S-Somewhat difficult 6-7 out of 10. The coveralls were too tight, also needed more room in the bag. Could not move around inside the bag--no room for my arms on the side, inside the bag.
Bl-Was not difficult to get on. No suggestions on improvements.

KIN V-Fairly simple. The sensor umbilical made it difficult to zip, however.
Ba-Not too bad, fairly simple. It would be better if the zipper was in the middle of the bag. The bag was kind of tight, so it was awkward to get to the side and zip it. Also, the baffles on the back made it difficult to roll over to reach the side. Some type of locking device on the zipper to keep it from being pulled down would be helpful, although the instrumentation umbilical probably helped pull it down.
J-Real easy to put on--seemed to need more room in the upper part of the outer bag, however.

(2) How was the fit of the oronasal mask?

DUI H-Awkward--It rode a little high around the eyes. I could feel the air being pulled in down past my chest during inhalation making me cold.
S-Uncomfortable--when laying on my back, the breathing tube would pull down and drag over my nose, and I wouldn't be able to breathe through my nose. Sitting up it would be better, I could help support the canister with my legs and take the pressure off the mask and my nose.
Bl-I thought it fit real well. If it had just been the mask without the instrumentation it wouldn't have been a problem.

KIN V-Good. Fit well, not real comfortable, but it fit well.
Ba-Fit pretty well. The instrumentation pulled, but not too bad.
J-Fit was tight. The straps were uncomfortable under my cheekbones. I noticed the cap design of the DUI and it looked like it would be more comfortable.

(3) Comment on the ability to breathe with the units. Easy? Difficult?

DUI H-At first to inhale was difficult, but I got used to it. Sometimes when I would move, the tube would be pinched off and make breathing difficult.

S-Not too bad, 5 on a scale of 1-10. Some resistance.
Bl-I could not breath through my nose because of congestion, so I had to breathe with my mouth. Not bad. I learned that the more I breathed, the warmer it got, so I would adjust my breathing to comfort level.

KIN V-Inhalation was difficult. I had to labor, and at times I could not get enough air. Exhalation was simple.
Ba-No problems. Fairly easy
J-Wasn't difficult, but there was some added pressure both ways.

(4) Was the temperature of the breathing gas acceptable?

DUI H-Yes
S-Would get real hot fast when I moved around. When I was still, it was comfortable.
Bl-Very Comfortable. I would adjust my breathing to make it cooler or warmer.

KIN V-Yes, one of the few comforts.
Ba-Yes, it was acceptable. The temperature started to decrease toward the end and was not as hot as I would have liked. It was a bit too warm in the beginning.
J-Yes, definitely. The cooling hole on the side helped some.

(5) Comment on the comfort of the sleeping bag system.

DUI H-Needed to be lifted off the deck. It was more comfortable when I was sitting up which I did 2/3 of the time. The deck was cold.
S-I needed more room, as mentioned in question #1.
Bl-Pretty comfortable. No problems.

KIN V-The system supported my back but not from my hips down. It was very uncomfortable. After 5 minutes, I deflated the bags and was more comfortable. I did not feel the coldness of the deck until after about 6 hours, then I started sitting up more.
Ba-The air baffles separate from each other and I could slip between them. One deflated and made it even more uncomfortable. If the baffles could extend further down it would be an improvement. I ended up pulling the baffles down so they were under my butt, and then pulled my legs up to keep them off the deck. The lower part of my body did not have inner protective clothing or the advantage of the baffles keeping me off the deck. They seemed to forget about the bottom half of the body.
J-The back rests look good, but they did not give much benefit. Maybe a flat air mattress would be better. There was a lot of dead space on the bottom and I couldn't keep my legs and feet warm--I would sit up Indian style. Pants with the system would help.

(6) How would you feel about spending 12-24 hours in the assembly?

DUI H-Probably could if I was off the deck.

S-During the last hour I started getting cold, it probably would have been pretty bad within another hour. I don't know.
Bl-I'm sure I would survive, but it would be miserable. Wouldn't want to do it.

KIN V-Could have done 12 hours if I had to, but I don't think I would have been conscious in 24 hours.
Ba-I think I could do 24 hours. After 12 hours, I was a little dizzy, so I don't think I would have functioned very well after 24.
J-I was tolerating the cold alright. I stopped because of the oronasal mask and my sinus pressure backing up. Very uncomfortable.

(7) Without initial training, do you think you would have been able to figure out proper use of the assembly?

DUI H-Yes
S-Yes, the directions were clear on the package.
Bl-Yes, the instructions were clear.

KIN V-Yes, no problem. I would have looked around for the bottoms, however, it seemed like they were missing.
Ba-Yes, Yes.
J-Oh Yes.

(8) At the completion of the test, would you have been able to physically perform in water transfer and other rescue procedures unaided?

DUI H-Yes
S-I didn't stop because of the cold, so I can't comment.
Bl-Yes, I could.

KIN V-Yes
Ba-Yes, Yes. After 24 hrs, I'm not sure, I probably would need assistance.
J-Yes, but not for any length of time. The canister change out was a killer, so I can see that rescue operations would be difficult. You go numb when you get out of the bag.

(9) Any other suggestions?

DUI H-No. (Longer zipper on bag, bag up off deck)*
S-No. (Both coveralls and bag not big enough, zipper go down further, modify mask so it doesn't pull on nose)
Bl-No.

KIN V-As mentioned, one way to improve would be to have pants--bottoms--that was the only part that got very cold.
Ba-Pants would help, as baffles only extend down the back. My legs touched the cold deck

more, so they needed covering. Pretty good system. The baffles did help, but I would like them attached to each other.

J-Pants added to the system. (More room in the outer bag in the upper area.)

(1 0) Why did you terminate?

DUI H-My back was cold.
S-Very uncomfortable orofacial mask, pain on bridge of my nose.
Bl-Cold and uncomfortable, with a headache. My shoulders, upper arms, feet, lower legs, and back were very cold.

KIN V-Very cold.
Ba-12 hour time limit. Diver was stopped by medical deck.
J-Getting to me in the end, my congestion with the uncomfortable orofacial mask.

*Comments made earlier by given diver are within parenthesis